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Brain trauma in head injuries presenting with and without concurrent skull fractures

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ABSTRACT

Head injuries and skull fractures may be problematic in cause and manner of death. Over a 10-year period, 54 cases showing head injuries were studied. Of thsese, 34 had skull fractures and 20 had no skull fractures. Virtually all decedents with skull fractures had brain injuries. The most common injury in both groups was motor vehicle accidents (MVA), in which 50% had skull fractures. In cases of skull fracture, brain lacerations, hemorrhages, and cerebral edema were common. Of 20 decedents with head injury but no skull fracture, most were accidents, and all but 3 cases had brain injury, although often relatively minor, except for atlanto-occiptital dislocation. There were significant differences between the two groups. Decedents with skull fractures tended to by younger (mean 35 years) compared to those with head injury only (mean 52 years) ($p = 0.0021$). The use of drugs or alcohol was more likely in decedents with skull fractures than in those with head trauma only ($p = 0.0431$). Mean abbreviated injury scale scores were higher for the face and head/neck of decedents with skull fractures, while significantly lower for chest and extremities, compared to decedents without skull fractures. Brain injury of some kind occurred in 90% of cases of head trauma, so a high level of suspicion should be placed in seeking skull fractures or brain injury.

1. Introduction

Head inquiries and skull fractures are common in clinical medicine and forensic pathology.[1,2] Records of these injuries date to antiquity when Hippocrates and Galen classified different types of skull fractures and developed methods of trephination as treatments.[3] Modern technology has been brought to bear on a famous ancient case, Tutankhamen, who was determined by radiographic means to have been spared from a suspected skull fracture.[4]

Head injuries and skull fractures remain problematic in modern times, too. In forensic pathology, there is often a question of what role the injury or fracture played in the cause of death, and how to consider the injuries in terms of manner of death. We have found these issues are especially important in accidents where civil litigation is possible, and in alleged homicides where criminal charges or degree of charges brought against a defendant may be considered.

We undertook this study in order to classify the role of head injuries and skull fractures in the cause and manner of death in cases in the community, and to seek commonalities or differences that may help determine the role of the injuries in the cause and manner of death. We anticipate these findings to be useful in discerning the degree of contribution of the head injury or skull fracture in future cases.

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2. Materials and methods

Cases over a 10-year period were reviewed from our files. The decedents were residents of Cedar Rapids or Eastern Iowa who had autopsies either because of legal requirements of the Iowa Code, or occasionally at family request to clarify issues that they wished to understand better on the death of their loved one. Complete autopsies were performed, including external examination of the body with and without clothing, internal examinations of the head, chest, and abdomen, and toxicological studies on blood.

Cases were selected for the presence of head injuries. Head injuries were defined as any structural, anatomic, or functional operation of the head that could be designated the cause of death or were coincident with other injuries led to death. Such findings included lacerations, abrasions, ecchymoses, hemorrhage, crepitus, or bleeding from one or both ears. The cases were then divided into groups based on the presence or absence of skull fractures. This finding was determined by both external examination of the head and open dissection of the head. Skull fractures were defined as disruptions in the integrity of the normal anatomy of the bony structures of the skull. Fractures could include hairline fissures that penetrated the full thickness of the calvarium and were evidenced by visual examination of the skull and confirmation by removal of the skullcap; multiple severe discontinuities of the integrity of the skull with one or more free-floating or absent pieces of bone; or even absence of a substantial portion of the head, as an immediate

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or proximate result of the circumstances that led to death. The major functional anatomic deficit that could be assessed postmortem was the integrity of the ligaments between the atlas and occiput, which was established by anomalous free rotation of the head in a body that was otherwise in rigor, and palpation of a discontinuity between the occiput and the atlas through the foramen magnum after the brain was removed.

Brain injuries were similarly defined as any structural or anatomic disruption of the normal configuration of the brain that could be traced proximally or immediately to the event that led to death. Such abnormalities included lacerations, hemorrhage in any site (internal, subdural, epidural, brainstem, etc.), edema, extrusion of cerebral material to the external environment through a discontinuity of the skull (e.g. one or more fractures, or significant loss of skull, head, or calvarium that would lead to concurrent loss of brain tissue), and atlanto-occipital dislocation (AOD), as described above.

Radiographs were occasionally required to find foreign objects (bullets or fragments of same), but were not used to establish skull or brain injury in decedents who were dead on arrival. In rare cases, the decedent arrived to hospital alive, and radiographs were obtained for treatment purposes, and were included in the record of the autopsy, but were not necessary for establishing our findings.

The two groups were subclassified based on manner of death, and further ranked within manner of death based on age. The cause of death in all cases was trauma caused by the incident that mandated the autopsy. The event that led to this trauma was designated. Other pertinent data were culled from autopsy, toxicology, and investigator reports. Injuries were further characterized using the abbreviated injury scale (AIS) for each body region used in the injury severity score (ISS).[5] If more than one anatomic region could be considered fatal by the AIS (score 6), both injuries were listed and scored, but the injury to the head was regarded as the immediate cause of death.

Comparisons of quantifiable data were performed using chi-square and *T*-tests.

3. Results

A total of 54 cases were recovered. All but 2 cases were dead at the scene, so no interval of survival could be established. The 2 short-term survivors are described following. While the specific brain injury may have been relatively minor in some cases of decedents with a skull fracture (e.g. a fall) compared to other decedents (e.g. MVA), the total AIS for the head/neck region regularly reached the score of 6 (fatal). The reasons for the severity of the head/neck AIS compared to other AIS areas were typically due to the degree, number, and location of skull fractures or neck injuries compared to other injuries in the AIS areas. Table 1 summarizes 34 decedents who suffered head injury including skull fractures. Table 2 summarizes 20 decedents with head injuries but no skull fractures.

All decedents had head injuries, whether they had concurrent fractures or brain injury without fracture. Most decedents with head injuries had brain injuries. All decedents with skull fractures had brain injuries except 1 case, in which the brain was too decomposed to assess. The most common mechanism of head injury in both groups was motor vehicle accidents (MVA) ($n = 30$), in which 50% had skull fractures and 90% had brain injuries.

Among decedents with skull fractures, a small majority ($n = 18$) died in accidents, the most common being MVA ($n = 15$), while a few sustained skull fractures from falls ($n = 3$). The second largest class was decedents who commit suicide ($n = 11$), of whom all sustained lethal gunshot wounds (GSW) to the head. The remaining 5 decedents were victims of homicides, of which 4 died from physical assaults and 1 died from GSW.

The external head injuries sustained by the decedents with skull fractures are summarized. Lacerations were common ($n = 29$), followed by crepitus ($n = 15$), ecchymoses ($n = 13$), hemorrhage from one or both ears ($n = 12$), abrasions and ($n = 11$).

The distribution of skull fractures was variable. Cases with multiple fractures, usually on both sides of the skull, included GSW ($n = 10$). Other sites of GSW injury were the frontal areas ($n = 1$) and temporal ($n = 1$). The other common source of multiple skull fractures was MVA ($n = 8$). In other MVA, the skull base was the identified fracture ($n = 3$), the frontal bones ($n = 2$), temporal ($n = 1$), and parietal ($n = 1$). Among falls, the skull base was involved in 3 cases, being the primary fracture in 2, an additional fracture with a large temporal fracture in 1. Among victims of physical assault, the parietal bones were most frequently broken ($n = 3$), while multiple fractures were seen in only 1 case.

The injuries to the brain that accompanied these skull fractures are also summarized in Table 1. In all but one case, the cadaveric remains were well-preserved, and could be examined thoroughly. In cases of skull fracture, brain lacerations were the most common injury seen ($n = 26$), sometimes including an AOD ($n = 4$), although this injury could occur without a cerebral laceration. Hemorrhages in different loci occurred commonly ($n = 17$), including parenchymal or pericerebral (e.g. subdural or epidural) sites. Cerebral edema was seen in many cases of skull fractures ($n = 12$), but didn't develop in all cases. Extrusion of cerebral matter through the fractures to the external environment occurred occasionally ($n = 6$). In 1 case, the body and brain were sufficiently decomposed that the brain had liquefied, and brain injuries could not be determined.

Injuries elsewhere in the body were also common ($n = 17$) including such diverse injuries as lacerations to the skin or soft tissue, lacerations to the spleen, liver, or other organs, fractures elsewhere in the body, and in 1 case, stab wounds. Such diverse injuries were most common in accident and homicide victims. Medical conditions were anatomically apparent in many decedents ($n = 14$), including fatty liver, heart disease, and a case of metastatic colon cancer. Different drugs were observed in many decedents ($n = 16$), including prescription antidepressants, painkillers, alcohol, and occasionally cannabinoids.

Most cases were dead at the scene, but 2 cases had documented periods of survival after the skull fractures occurred. In fact, 1 was lucid and under treatment for comorbid conditions before the presence of the skull fractures manifested. Curiously, both patients had been drinking heavily, and were concurrently sobering up as the skull fractures led to hemorrhage and death. One decedent was a woman who was being treated after her fall down a flight of stairs; the other was a man who was treated for injuries from a fight.

The AIS scores for each body region in decedents with skull fractures are also presented in italics in Table 1, below the descriptions of the various injuries. The presumptive cause of death in these decedents was the skull fractures and brain trauma, although in 3 cases, there were sufficient injuries in the chest region alone to cause death, while in 1 case, injury to the face was sufficient to cause death, irrespective of skull or brain injury. The mean AIS scores for each region were as follows: face, 3.29; head and neck, 6.0; chest, 0.97; abdomen 0.62; extremities 0.71; external, 0.56.

Table 2 summarizes 20 decedents with head injury but no evidence of skull fracture. All but 2 of these decedents were victims of accidents ($n = 18$). The majority were involved in MVA ($n = 16$), a small number in falls ($n = 2$), 1 homicide and 1 natural death.

Documented external head injuries in this group included lacerations ($n = 12$), abrasions ($n = 12$), or ecchymoses ($n = 6$). Bleeding from the ear was rare ($n = 1$). Intracranial or brain injuries were mostly different types of hemorrhages ($n = 13$), cerebral edema ($n = 6$), and a laceration of the brain ($n = 1$). AOD was observed in

Table 1
Decedents with head injury and skull fractures

Case	A/S	Head injuries	Skull fractures	Brain injuries	Other findings	Event	Manner
1.	57 F	L, Cr, ear	M	L, H, X	Other fractures	MVA	Accident
		Face: 1	*Head/neck: 6*		*Chest 1; abdomen 0; extremities 2; external 0*		
2.	53 M	L, A, Cr, Ec	M	H, E	Coronary artery disease, fatty liver, hepatitis	MVA	Accident
		Face: 4	*Head/neck: 6*		*Chest 0; abdomen 2; extremities 0; external 0*		
3.	48 F	L, A, Cr, Ec	M	L, E	Lacerations, left body, spleen	MVA	Accident
		Face: 4	*Head/neck: 6*		*Chest 2; abdomen 3; extremities 2; external 2*		
4.	38 M	L, A	M	L	Carotid laceration, hemothorax	MVA	Accident
		Face: 4	*Head/neck: 6*		*Chest 4; abdomen 1; extremities 3; external 2*		
5.	30 F	L, A	F	H, E	Previous salpingectomy	MVA	Accident
		Face: 2	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 0; external 0*		
6.	27 M	A, E, ear	T	L, H, AOD	Multiple lacerations, leg fracture, EtOH	MVA	Accident
		Face: 2	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 2; external 0*		
7.	25 M	A, Cr	B	L,E	EtOH, benzodiazepines	MVA	Accident
		Face: 3	*Head/neck: 6*		*Chest 2; abdomen 2; extremities 0; external 0*		
8.	24 M	L, A, Ec	M	L	Thorax, abdominal injuries	MVA	Accident
		Face: 3	*Head/neck: 6*		*Chest 3; abdomen 3; extremities 0; external 0*		
9.	23 F	L, ear	P	L, E, X	Lacerations, skin	MVA	Accident
		Face: 1	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 0; external 2*		
10.	21 M	L, A, Ec, ear	B, O	L, E, AOD	Lacerations, skin	MVA	Accident
		Face: 2	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 0; external 2*		
11.	19 F	L, A, Ec	F	L, E, H	Liver, spleen, abdominal hemorrhage	MVA	Accident
		Face: 3	*Head/neck: 6*		*Chest 0; abdomen 4; extremities 1; external 0*		
12.	18 M	A, Ec, ear	B	AOD	Herniation heart into chest, hemorrhage, THC	MVA	Accident
		Face: 2	*Head/neck: 6*		*Chest 6; abdomen 0; extremities 1; external 1*		
13.	17 M	L, A, Cr	M	L, E, H	Lacerations, fatty liver, EtOH	MVA	Accident
		Face: 3	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 2; external 1*		
14.	16 M	L, Cr	M, B	L, X	Fractures arm, abrasions	MVA	Accident
		Face: 5	*Head/neck: 6*		*Chest 1; abdomen 0; extremities 1; external 1*		
15.	15 F	L, Ec, Cr	M	L, X, AOD	Massive external, internal injuries	MVA	Accident
		Face: 5	*Head/neck: 6*		*Chest 6; Abdomen 3; Extremities 2; External 2*		
16.	68 F	L	B	H, E	Coronary artery disease, fatty liver	Fall	Accident
		Face: 1	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 1; external 0*		
17.	48 M	Ec, ear	B	H, E	Fatty liver, THC	Fall	Accident
		Face: 3	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 1; external 0*		
18.	40 F	L, Ec, ear	T, B	H, E	Skin lacerations, Fatty liver, EtOH	Fall	Accident
		Face: 3	*Head/neck: 6*		*Chest 1; abdomen 0; extremities 1; external 0*		
19.	69 M	L, Cr	F	L, AOD	Colon carcinoma, painkillers	GSW	Suicide
		Face: 6	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 0; external 0*		
20.	64 M	L, Ec	M,B	L, H	Coronary artery disease	GSW	Suicide
		Face: 4	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 0; external 0*		
21.	63 F	L	T	L, H	Depression, drugs	GSW	Suicide
		Face: 3	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 0; external 0*		
22.	52 M	L, Cr	M	L	Fatty liver, coronary artery disease, hepatitis C, THC	GSW	Suicide
		Face: 5	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 0; external 0*		
23.	51 M	L	M	L, X	Psychiatric drugs	GSW	Suicide
		Face: 4	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 0; external 0*		
24.	48 M	L, Cr, ear	M, B	L, H	Hypertension, fatty liver, Crohn's disease	GSW	Suicide
		Face: 4	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 2; external 0*		
25.	43 M	L, Cr	M	L, H	Antidepressants, hepatitis	GSW	Suicide
		Face: 5	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 0; external 0*		
26.	35 M	L, Cr	M	L, H	Fatty liver, EtOH	GSW	Suicide
		Face: 4	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 0; external 0*		
27.	31 M	L, Cr, ear	M	L	Fatty liver, EtOH	GSW	Suicide
		Face: 5	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 0; external 0*		
28.	26 M	L, ear	M	L	Multiple drugs	GSW	Suicide
		Face: 2	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 0; external 1*		
29.	22 M	L, Cr, ear	M	L, H	Fatty liver, EtOH	GSW	Suicide
		Face: 2	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 0; external 0*		
30.	39 M	Ec	P	L, H	Hepatitis C, left black eye, EtOH	Assault	Homicide
		Face: 2	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 0; external 0*		
31.	30 F	L, Ec	P, B	H, E		Assault	Homicide
		Face: 4	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 0; external 0*		
32.	24 M	L, Cr	M	Decomposed	Fatty liver, gastrointestinal hemorrhage	Assault	Homicide
		Face: 4	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 0; external 0*		
33.	23 M	L, ear	M, B	L, H	Burns, attempted incineration	GSW	Homicide
		Face: 3	*Head/neck: 6*		*Chest 0; abdomen 0; extremities 0; external 0*		
34.	18 F	L, stab wounds	P	L, X	Multiple stab wounds	Assault	Homicide
		Face: 4	*Head/neck: 6*		*Chest 6; abdomen 3; extremities 3; external 5*		

Head injuries: L, laceration; A, abrasions; Ec, ecchymoses; Cr, crepitus; ear, hemorrhage from ear(s).
Skull fractures: M, multiple; B, base; P, parietal; F, frontal; T, temporal; O, occipital.
Brain injuries: L, laceration; H, hemorrhage; E, edema; X, extrusion of brain to external environment; AOD, atlanto-occipital dislocation.
Other findings: EtOH, ethanol; THC, tetrahydrocannabinol.
Abbreviated injury scale (AIS) score by anatomic region reported in italics beneath lines describing the injuries.

Table 2
Decedents with head injury but no skull fractures

Case	A/S	Head injuries	Brain injuries	Other findings	Event	Manner
1.	88 M	L, A	SAH, E	Rib fractures, hemorrhage right lung, coronary artery disease	MVA	Accident
		Face: 2	*Head/neck: 5*	*Chest 4; abdomen 0; extremities 3; external 1*		
2.	88 M	L, A, ear	SAH	Rib fractures, right hemothorax, left lung hemorrhage	MVA	Accident
		Face: 4	*Head/neck: 3*	*Chest 5; abdomen 0; extremities 0; external 0*		
3.	70 F	A		Rib, cervical spine, humerus fractures	MVA	Accident
		Face: 2	*Head/neck: 0*	*Chest 5; abdomen 0; extremities 2; external 0*		
4.	56 M	A		Methamphetamine, THC	MVA	Accident
		Face: 2	*Head/neck: 0*	*Chest 0; abdomen 0; extremities 0; external 0 (asphyxiation)*		
5.	51 M	A	AOD	Internal bleeding, right hemothorax, femoral and other fractures	MVA	Accident
		Face: 1	*Head/neck: 6*	*Chest 6; abdomen 2; extremities 3; External 0*		
6.	50 M	A	SAH, H, AOD	EtOH, coronary artery disease	MVA	Accident
		Face: 2	*Head/neck: 6*	*Chest 0; abdomen 1; extremities 1; external 2*		
7.	48 M	L	E	rib fractures	MVA	Accident
		Face: 3	*Head/neck: 2*	*Chest 3; abdomen 0; extremities 0; external 0*		
8.	44 F	L	SAH, AOD	Heart laceration, hemothorax, liver laceration	MVA	Accident
		Face: 2	*Head/neck: 6*	*Chest 6; abdomen 5; extremities 4; external 2*		
9.	42 F	L	SAH, AOD	EtOH	MVA	Accident
		Face: 2	*Head/neck: 6*	*Chest 0; abdomen 0; extremities 2; external 0*		
10.	40 F	L, A	SAH, E	Ruptured spleen, retroperitoneal hemorrhage, long bone and rib fractures	MVA	Accident
		Face: 0	*Head/neck: 2*	*Chest 2; abdomen 3; extremities 3; external 0*		
11.	34 F	L, A, Ec		T12 spinal cord transection, hemothorax, fractures	MVA	Accident
		Face: 3	*Head/neck: 0*	*Chest 6; abdomen 6; extremities 4; external 3*		
12.	32 M	L, A	SAH	Hemothorax, spinal transection, transection aorta, fractures, laceration liver	MVA	Accident
		Face: 2	*Head/neck: 3*	*Chest 6; abdomen 5; extremities 3; external 2*		
13.	31 M	L, A	SAH	laceration of heart, lungs	MVA	Accident
		Face: 3	*Head/neck: 2*	*Chest 6; abdomen 5; extremities 4; external 2*		
14.	26 M	L, A, E	SAH	Hemothorax, crushed ribs, fractures extremities, fatty liver	MVA	Accident
		Face: 2	*Head/neck: 2*	*Chest 6; abdomen 2; extremities 3; external 0*		
15.	19 M	A, Ec	L	Laceration of aorta	MVA	Accident
		Face: 3	*Head/neck: 2*	*Chest 6; abdomen 0; extremities 2; external 0*		
16.	19 F	A, Ec	SAH, AOD	Opiate	MVA	Accident
		Face: 3	*Head/neck: 6*	*Chest 0; abdomen 0; extremities 2; external 0*		
17.	87 F	Ec	H, E	Congestive heart failure, coronary artery disease	Fall	Accident
		Face: 2	*Head/neck: 4*	*Chest 2; abdomen 0; extremities 0; external 0*		
18.	74 F	Ec	H, E	Constrictive pericarditis, coronary artery disease	Fall	Accident
		Face: 0	*Head/neck: 5*	*Chest 0; abdomen 0; extremities 2; external 3*		
19.	48 M	L	E	Lacerations/incisions neck, lacerated carotid artery	Assault	Homicide
		Face: 3	*Head/neck: 6*	*Chest 0; abdomen 0; extremities 2; external 0*		
20.	86 F	L, Ec	CVA	Diabetes	CVA	Natural
		Face: 3	*Head/neck: 6*	*Chest 0; abdomen 0; extremities 0; external 1*		

Head injuries: L, laceration; A, abrasion; Ec, ecchymoses; ear, hemorrhage from ear(s).
Brain injuries: L, laceration; H, hemorrhage NOS; SAH, subarachnoid hemorrhage; EH, epidural hematoma; E, edema; AOD, atlanto-occipital dislocation; CVA, cerebrovascular accident.
Other findings: EtOH, ethanol; THC, tetrahydrocannabinol.
Abbreviated injury scale (AIS) score by anatomic region reported in italics beneath lines describing the injuries.

cases of MVA and 1 fall ($n = 4$). A small number of cases showed no discernable brain injury ($n = 3$).

Other injuries to the body in these non-skull-fracture decedents were very common, including fractures, internal hemorrhages, or organ injuries ($n = 18$). Incidental comorbid medical conditions were relatively rare ($n = 5$). Drug or alcohol use was also relatively rare ($n = 4$).

The AIS scores the body regions of decedents with head injury but without skull fractures are also presented in Table 2. It is noteworthy that, even without skull fractures, the head and neck region sustained a lethal injury in 6 cases, 4 from AOD, 1 from laceration of the carotid artery, and 1 from cerebrovascular accident (CVA). In 7 cases, the cause of death was likely due to trauma in the chest region, but in 2 of these cases there was a concurrent AOD that could just as likely caused death. The mean AIS scores for each region were as follows: face, 2.20; head and neck 3.6; chest, 3.15; abdomen 1.45; extremities, 2.10; external, 0.80.

There were no differences between the groups of decedents with skull fractures versus those with head injury without skull fractures based on gender, presence of cerebral edema, intracranial or brain hemorrhage, external ecchymoses, AOD, death by homicide, or concurrent medical conditions. Decedents with fractures were more likely to have concurrent head lacerations, but not at a strongly significant level ($p = 0.0505$). Similarly, abrasions of the head were more likely in decedents without skull fractures, but not at a strongly significant level ($p = 0.0561$).

However, there were several significant differences. All decedents with skull fractures were likely to have brain injuries of some kind, while those with head injury but no skull fracture occasionally were less likely to have brain injuries ($p = 0.0487$). Decedents with skull fractures tended to by younger (mean 35 years) compared to those with head injury only (mean 52 years) ($p = 0.0021$). This age difference is maintained in view of the cause of the skull fracture, as well; victims of MVA with skull fractures were younger (mean = 29 years) than their counterparts in MVA without skull fracture (mean = 46 year) ($p = 0.0118$). The pattern was true of all other deaths with or without skull fractures, too, including suicides, falls, assaults, and natural death. The age of these decedents with skull fractures (mean 42 years) was significantly younger than that of those without skull fractures (mean 74 years) ($p = 0.0022$).

The use of drugs or alcohol was more likely in decedents with skull fractures than in those with head trauma only ($p = 0.0431$). Among decedents with skull fractures, the unique external head injury compared to decedents without skull fractures was the significant presence of crepitus ($p = 0.003$). Decedents with skull fractures were more likely to have hemorrhage from their ears on external examination ($p = 0.0186$), and lacerations of the brain

were far more likely in this group ($p = 0.0001$). Decedents with head injury but no skull fracture were more likely to die in accidents compared to decedents with skull fractures ($p = 0.0068$). They were also more likely to have other serious injuries elsewhere in their bodies ($p = 0.0063$). Decedents without skull fractures were more likely to die in MVA than were those with skull fractures ($p = 0.0121$). Conversely, decedents with skull fractures were far more likely to die from suicide than were those without skull fractures ($p = 0.0001$).

One should note, however, that many of these differences were not maintained if we considered the comparable incidents of MVA between the two groups. Skull fractures were equally likely to occur as not when there were major injuries elsewhere.

Only one natural death was recorded. This decedent had a laceration and ecchymoses of the head and was found to have suffered a CVA. It is likely that this case is one in which the brain injury occurred before the head injury, i.e. an elderly patient who fell as a result of the CVA and sustained head injuries.

Many significant differences were found between the mean AIS scores of decedents with skull fractures compared to the mean AIS scores of decedents without skull fractures. The mean AIS score for the face among decedents with skull fractures (3.29) was significantly higher than among decedents without skull fractures (2.20) ($p = 0.0020$), as were the scores for head and neck trauma in decedents with skull fractures (6.0) compared to for decedents without skull fractures (3.6) ($p = 0.0001$). On the other hand, the mean AIS scores for the chest were significantly lower for decedents with skull fractures (0.97) compared to decedents without skull fractures (3.15) ($p = 0.0010$), and also significantly lower for the extremities among decedents with skull fractures (0.71) compared to decedents without skull fractures (2.10) ($p = 0.0002$). There were no statistically-significant differences between the mean AIS scores between the two groups for injuries of the abdomen and external injuries.

4. Discussion

The present study was undertaken in order to provide data for discussion, deposition, and testimony about the role of head and brain trauma in death in cases that lead to litigation or criminal prosecution. We have found that summary, collective literature on these incidents is rare. There are many specific case reports that may have some relevance to a certain case, and there are many large studies of head injury, coma, and treatment. But as regards the relationship between different types of events/incidents, cause and manner of death, and the relationship between the particular contributions of skull fractures and concurrent brain injury or non-injury, such literature is not readily available without inference from sources that do not address this particular question. In a recent homicide case the author experienced, he was unable to provide objective data regarding the role of head trauma, rather relying on impressions and anecdotal experiences. While such reports, skillfully delivered, may be persuasive to a jury, nothing is as reliable as thoughtfully-defined, collected, and analyzed data for scientific inquiry; and such data also provides rebuttal for disputes that arise in the courtroom or at the morbidity and mortality conference. Moreover, there were novel findings from this study, which merit report and discussion.

Brain injury is a common problem in trauma and forensic medicine. A large study of 4660 patients with brain injury showed that 28% had concurrent skull fractures, and greater than half of them died within 24 h.[2] In the present study, all decedents with skull fractures had some form of concurrent brain injury, except for one man whose brain was too decomposed to examine. In this case, based on this study, it would be rational to deduce that he also suffered brain injury that would be contributory and probably causative of death. By contrast, a few decedents with head injury and no skull fracture had no discernible brain injuries. In our data, men and women appeared to be equally likely to suffer head injuries with or without skull fractures. Cerebral edema, intracranial hemorrhage, and AOD were equally likely in decedents with or without skull fracture, and each sequela was potentially fatal on its own. The prevalence of C1–C2 dislocation and AOD in the presence or absence of skull fractures has been reported previously.[6]

MVA were a major cause of mortality in both of our groups. Fatalities are common in this population, up to 71% within 24 h of the incident.[7] Skull fractures, cerebral contusions, lacerations, and hemorrhages all contribute to mortality.[7] Intrusion of another vehicle or occupant ejection have been cited as major causes of skull fractures in MVA.[8]

Lacerations of the head were more common in decedents with skull fractures. This tendency was probably due to the severe head injuries caused by GSW, which by nature inflicted some form of laceration, by producing an entrance or exit wound or both. By contrast, abrasions tended to be more common in decedents without skull fractures; however, abrasions were approximately equal in decedents of MVA with or without skull fractures. The tendency for decedents without skull fractures to have more abrasions appears also to have been due to the major contribution of GSW to decedents with skull fractures, who were less likely to have an abrasion as a result of their locally-inflicted injuries.

There is no obvious reason for the younger age of decedents with skull fractures, a fact that appears to be true regardless of the reason for the skull fracture or lack thereof (MVA, GSW, fall, assault, etc). Other studies have shown an older male predominance among patients with chronic subdural hematoma, often among alcoholics or as a result of falls.[9] Ground level falls also have an elderly male predominance, often with preexisting disease, such as cardiovascular disease; 37% of these patients sustained skull fractures, while 85% developed subdural hematomas.[10] The increased presence of drugs or alcohol in victims of head injury with skull fracture was more straightforward to understand. The reason of impairment for MVA was a risk for either group, and the use of psychiatric medications in the group of suicide victims suggests underlying risk factors such as depression.

The significant prevalence of blood in the ears of decedent with skull fractures is basically one of anatomy. Disruption of cranial bone structure and circulation, especially around the skull base, led to increased likelihood of hemorrhage at this site. Interestingly, skull base fractures have also been associated with intra-corporeal sequestration of blood.[11] Likewise, the chances of cerebral lacerations is significantly increased when bone is broken, due to transmission of force sufficient to break cranial bones, and the presence of sharp, irregular bone edges or fragments around or in the brain.

The increased likelihood that decedents of head injuries without skull fracture to die in MVA appears to be an artifact of the high prevalence of skull fractures caused by GSW. If this subgroup was not counted, there was no greater likelihood of a victim of a MVA to suffer a skull fracture or not. The same observation can be made regarding serious injuries in MVA victims with or without skull fractures. The localized injury of a direct GSW to the head limited injuries elsewhere in the body, while MVA could inflict massive injury at multiple sites, regardless of skull fractures. Another study has correlated the presence of skull fractures with multiple injuries elsewhere in the body after an MVA.[12] Among our data, the increased likelihood of a decedent without skull fracture compared to decedents with skull fracture dying in a MVA disappeared when the contribution of GSW to skull fractures was not considered.

Similarly, when GSW was considered separately from MVA and other causes of skull fractures, the increased likelihood of skull fracture in this group was most likely a result of the nearly-unavoidable

skull fracture caused by a GSW to the head, and not due to an obscure mechanism that was only discerned by statistical correlations.

The AIS scores are a valuable enhancement to compare the injuries sustained by these decedents systematically, although somewhat subjectively.[5] Originally designed for use in triage, the AIS ranks the injuries in the 5 body regions between 1 (minimal) to 6 (unsurvivable). The top three scores from the AIS are squared and summed, leading to the ISS. A score of 6 in any of the 5 body regions is automatically considered an ISS of 75 (fatal); otherwise, the ISS is calculated as described, and can be further used to calculate the probability of survival. In our study, all cases with skull fractures and/or significant brain injury were considered AIS score 6 for the head and neck region, i.e. a fatal injury. This conclusion was based on the combined effects of number and location of skull fractures, the extent of brain injuries (even if not by themselves fatal), and the presence of AOD, which is included in the neck region of the head/neck AIS score. The other injuries these decedents sustained were also evaluated and scored, and all injuries in all body regions were scored in the decedents with head injury but without skull fractures.

Interesting patterns emerged. Not surprisingly, the AIS scores for head and neck trauma, and for facial trauma, were significantly higher in the victims of skull fractures compared to those without skull fractures. On the other hand, decedents without skull fractures were likely to have significantly higher AIS scores for chest and extremities trauma. This outcome might be expected, since vital organs typically need to be significantly injured to cause death; the chest is a good candidate for lethal injuries, due to the danger to vital heart, lung, and circulatory functions. Likewise, the extremities are probably at higher risk of significant injury in decedents without skull fractures because they are involved in incidents that inflict trauma to multiple sites, mostly accidents, especially MVA. While MVA was also common among decedents with skull fractures, the AIS scores of the other regions were less significant because of fatal head and neck injuries. Finally, AIS scores did not differ statistically among decedents with or without skull fractures in the abdomen or external sites, although they trended to be more common in the decedents without skull fractures ($p = 0.0725$), probably for the same reasons that the chest and extremity injuries were more severe in the decedents without skull fractures.

In summary, the present study yielded several significant findings for clinical medicine and forensic studies of the cadaver with head injuries. MVA are a common source of head trauma, and skull fractures occurred in 50% of cases; however, brain injury of some kind occurred in 90% of cases with or without skull fracture, so a high level of suspicion should be placed in seeking skull fractures or brain injury in any cases of head trauma. GSW are another significant cause of skull fractures. Regular practices of physical examination should be performed both clinically and pathologically, particularly palpation for crepitus and examination of the ears, both significantly implying the presence of skull fractures. Younger persons appear to be at significantly greater risk of fatal skull fractures from any cause than do older persons in our study. Toxicology studies should be performed in all decedents, and may be significantly more likely to be positive and possibly contributory in decedents with skull fractures. Skull fractures virtually never left the brain without some form of injury, while head trauma without skull fracture occasionally did. AIS scores differ significantly and systematically between the two groups. Finally, there are many protocols established to determine the risk of serious trauma based on consciousness and clinical and radiologic studies.[13,14] Our study affirms that a doctor or pathologist should evaluate any visible head injury thoroughly, since the injury may be part of more-serious injuries in the skull that do not manifest immediately.

Conflict of interest statement

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